Cryogenic Stopping cell For the **L**ow **E**nergy **B**ranch of Super FRS at FAIR

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NUSTAR Collaboration

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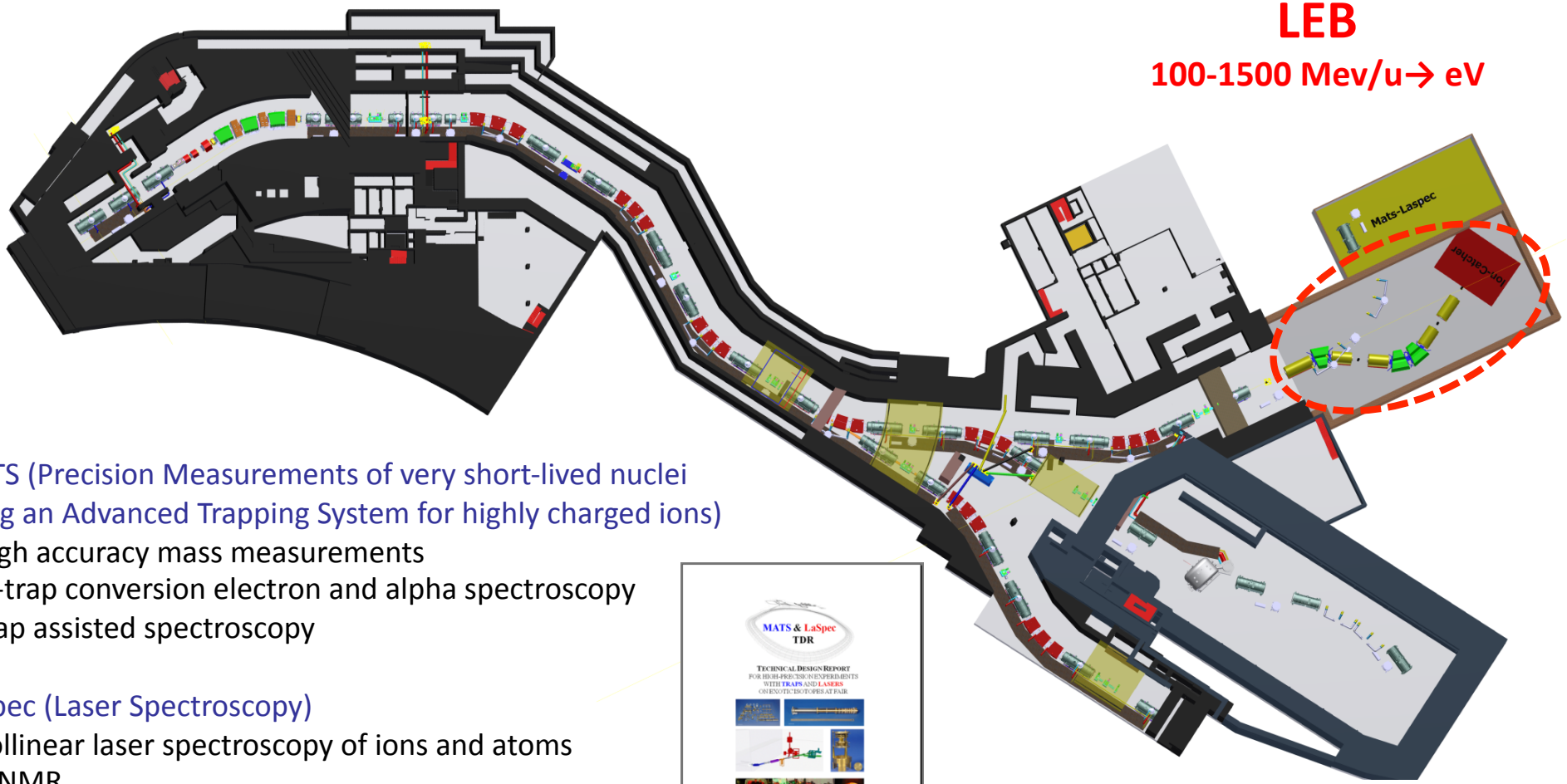
13-17 October 2014, Das Wormser

Motivation: Low Energy Branch of the Super-FRS

LEB: High-precision experiments with in-flight separated exotic nuclei almost at rest,
(production by projectile fragmentation / fission)

- universal and fast production
- high selectivity
- cooled exotic nuclei



MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly charged ions)

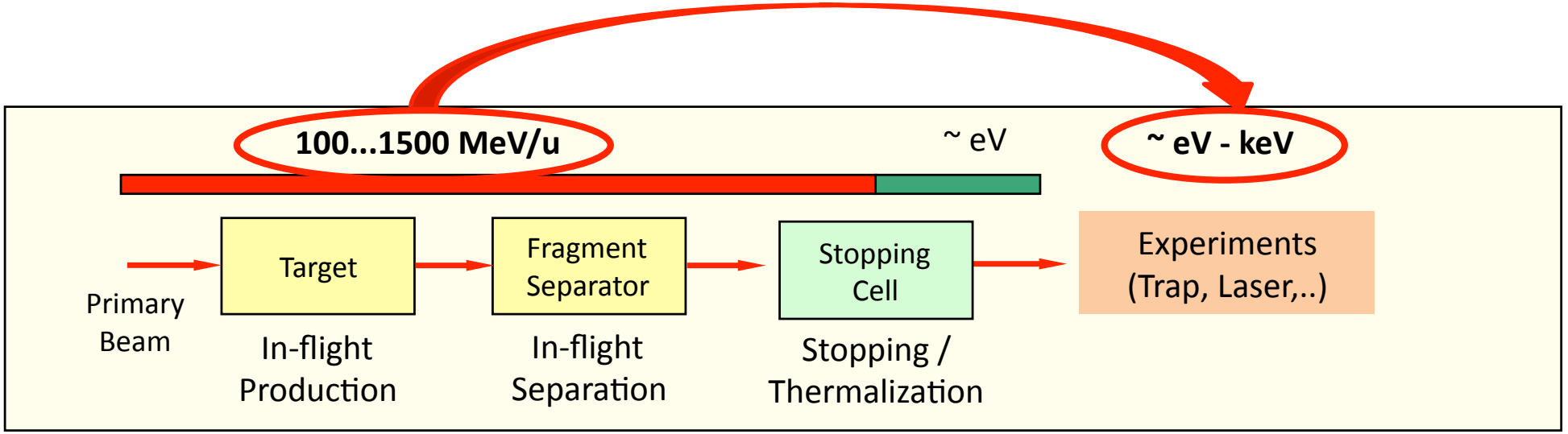
- High accuracy mass measurements
- In-trap conversion electron and alpha spectroscopy
- Trap assisted spectroscopy

LaSpec (Laser Spectroscopy)

- Collinear laser spectroscopy of ions and atoms
- β-NMR
- Resonance ionization spectroscopy

Eur. Phys. J. Special Topics 183 (2010) 1

Low Energy Experiments at In-flight Facilities



Gas Cell Experiments – challenges

Efficient stopping

- Range straggling

➔ Momentum compression
➔ High density operation

Beam purity

- Adducts and molecules
- Isotopic/Isobaric contamination

➔ Cleanliness
➔ Mass separator

Efficient extraction

- Decay losses
- Recombination losses
- Space charge/Plasma effects

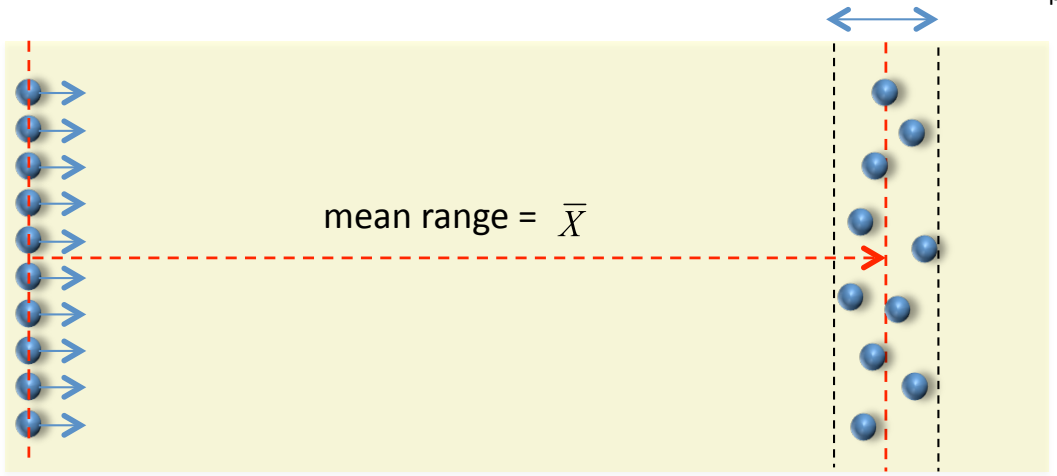
➔ Fast extraction
➔ Cleanliness
➔ High DC fields

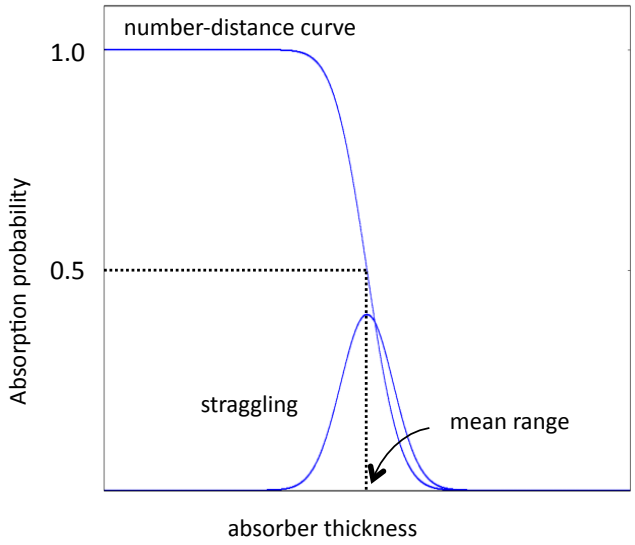
Efficient stopping

Range & range straggling

$\Delta x = 0, \Delta p = 0$

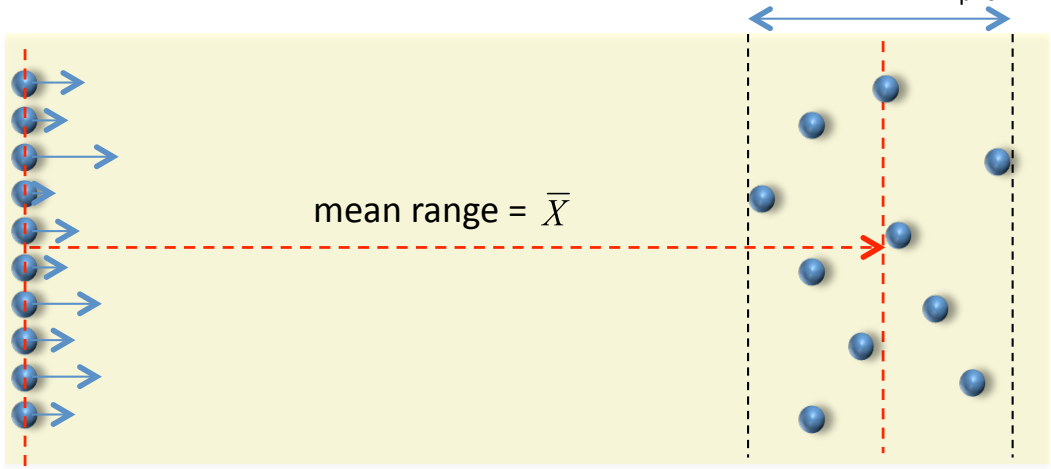
Range straggling : $\Delta x_{\Delta p=0} > 0$

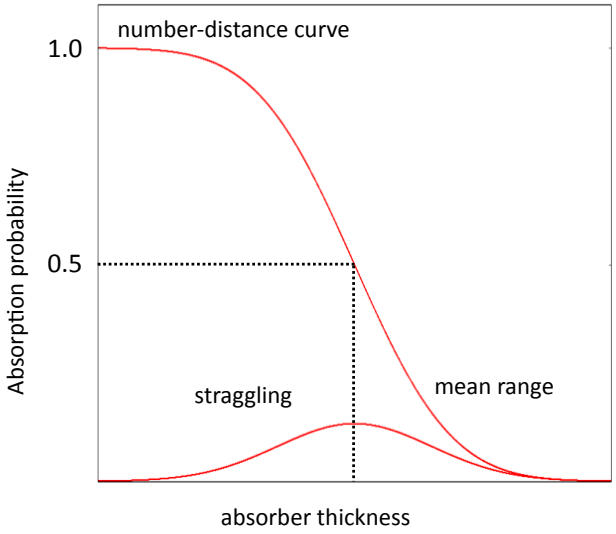




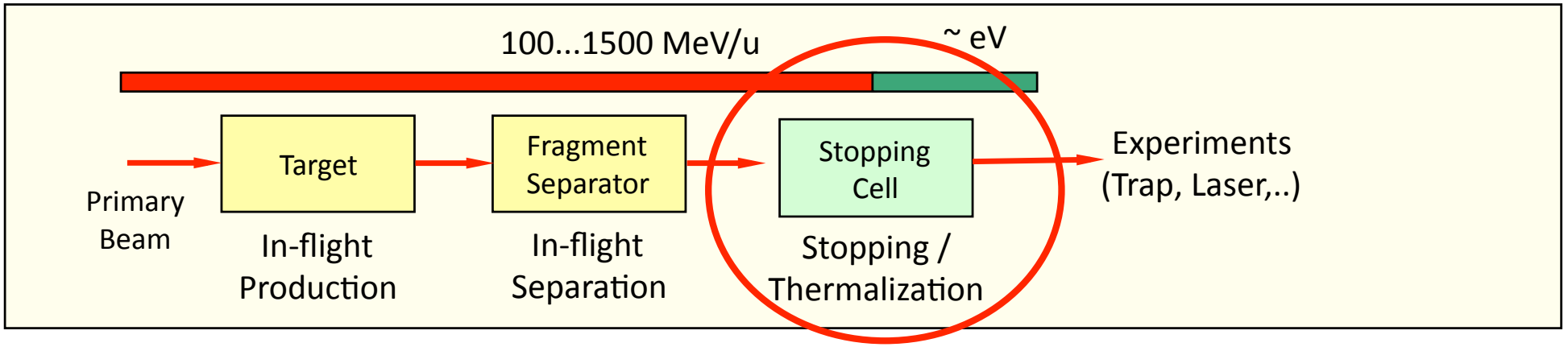
$\Delta x = 0, \Delta p \neq 0$

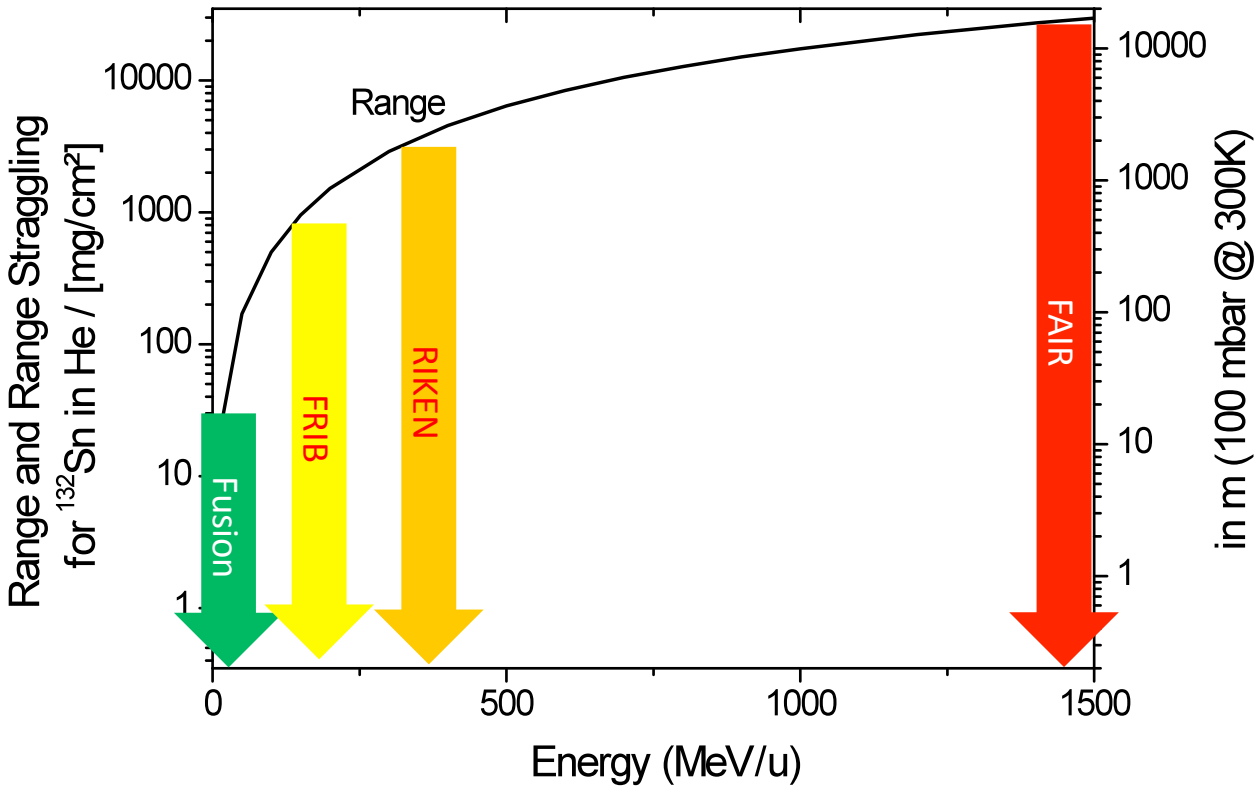
Range straggling : $\Delta x_{\Delta p \neq 0} > \Delta x_{\Delta p=0}$



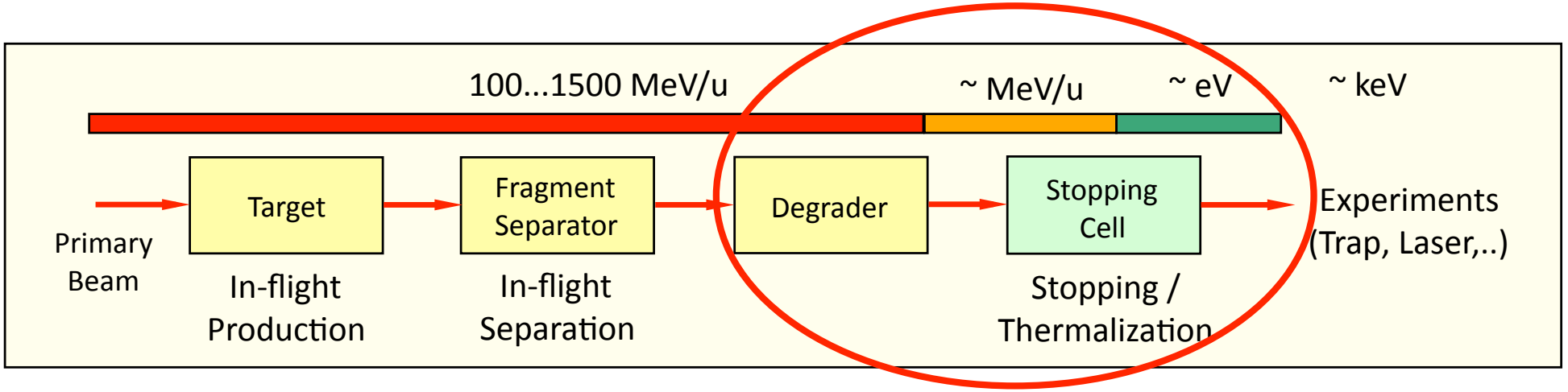


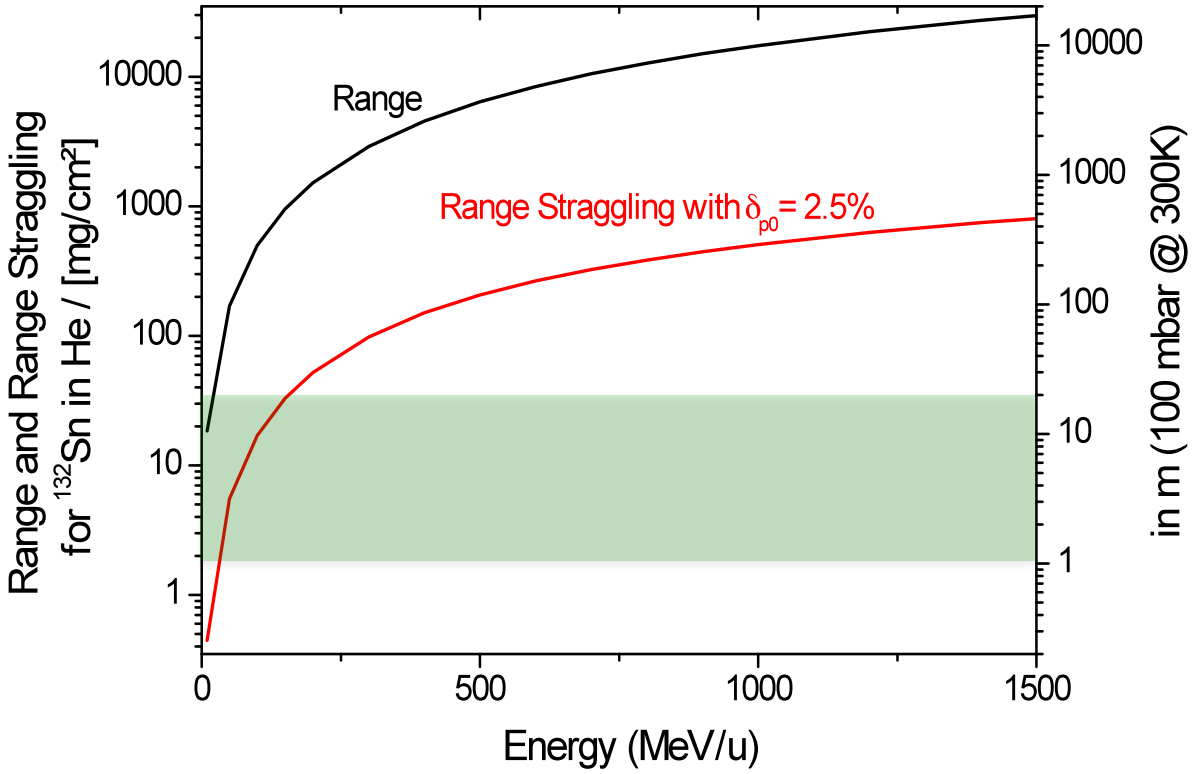
Low Energy Experiments at In-flight Facilities



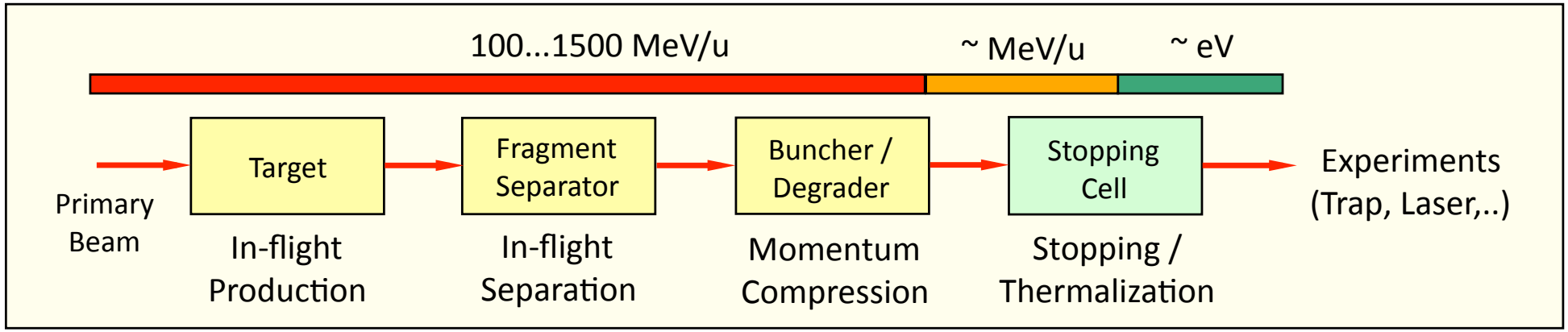


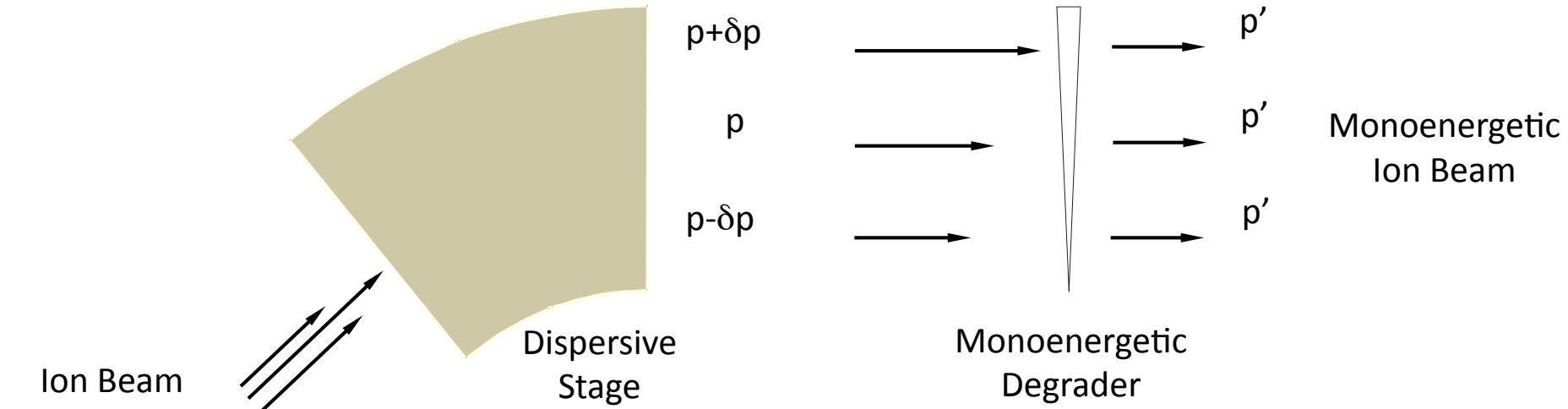
Low Energy Branch (LEB) of Super FRS at FAIR





LEB: Momentum Compression

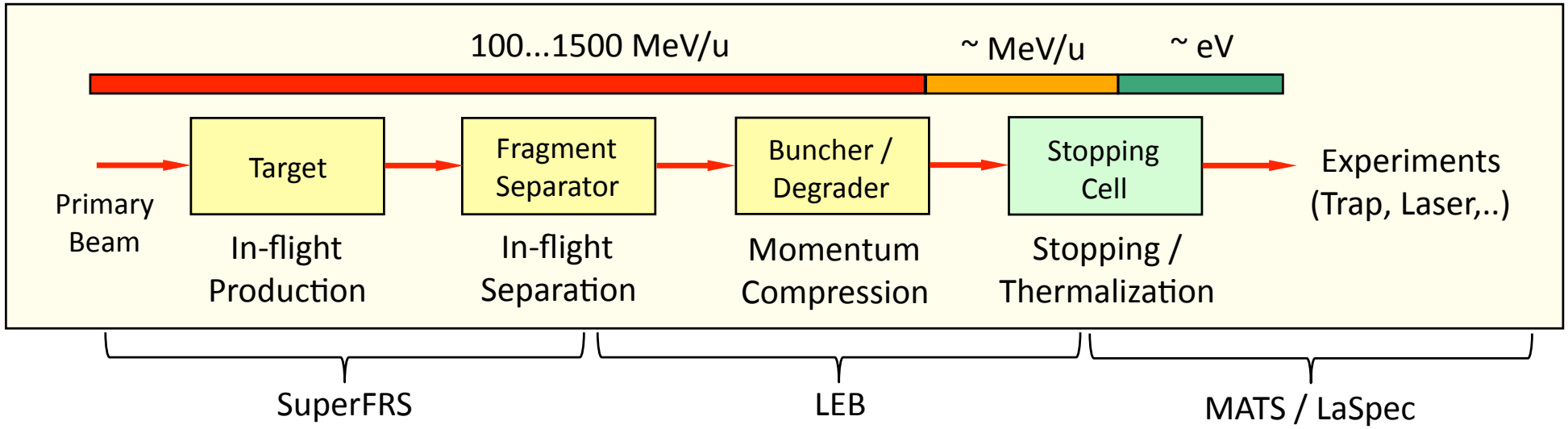


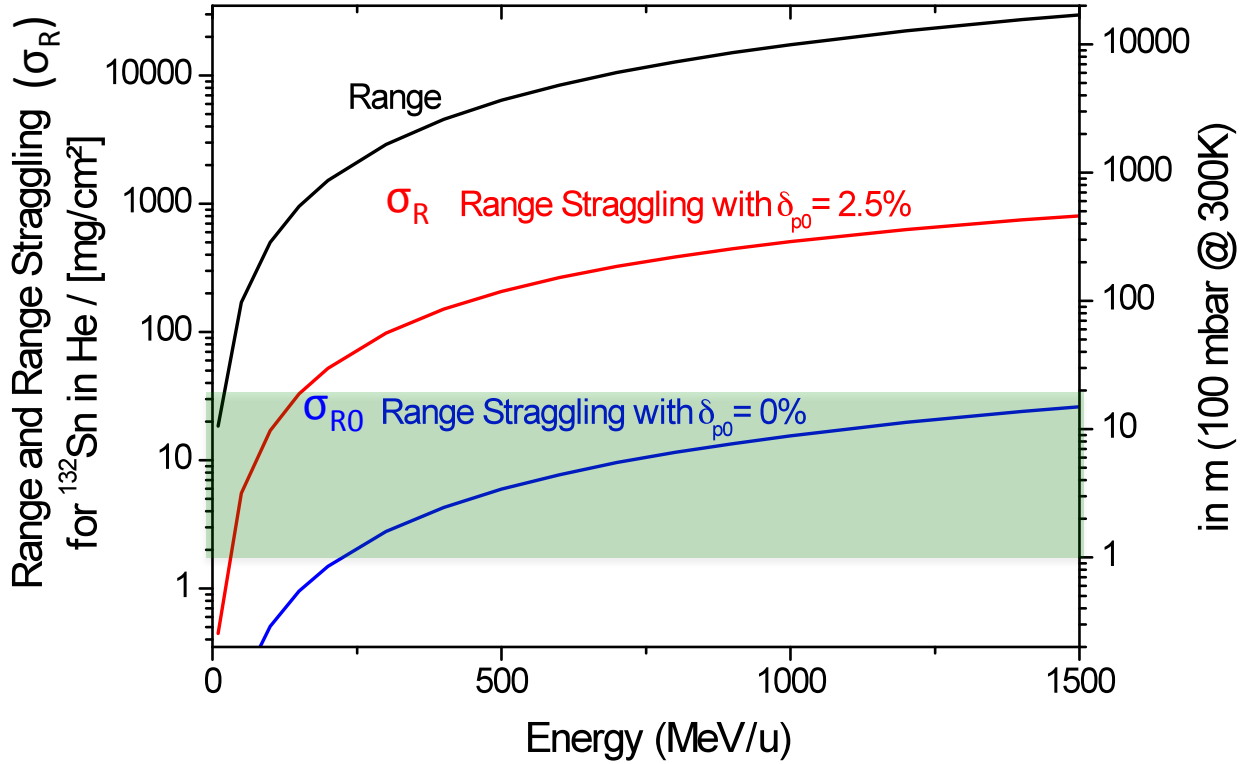


- Ion beam is spatially separated by its momentum in a dispersive stage
- Monoenergetic degrader reduces momentum spread
- Allows stopping in realistic amount of material

H. Weick et al., NIM B 164 (2000) 168

LEB: Momentum Compression





Range bunching at LEB of SFRS

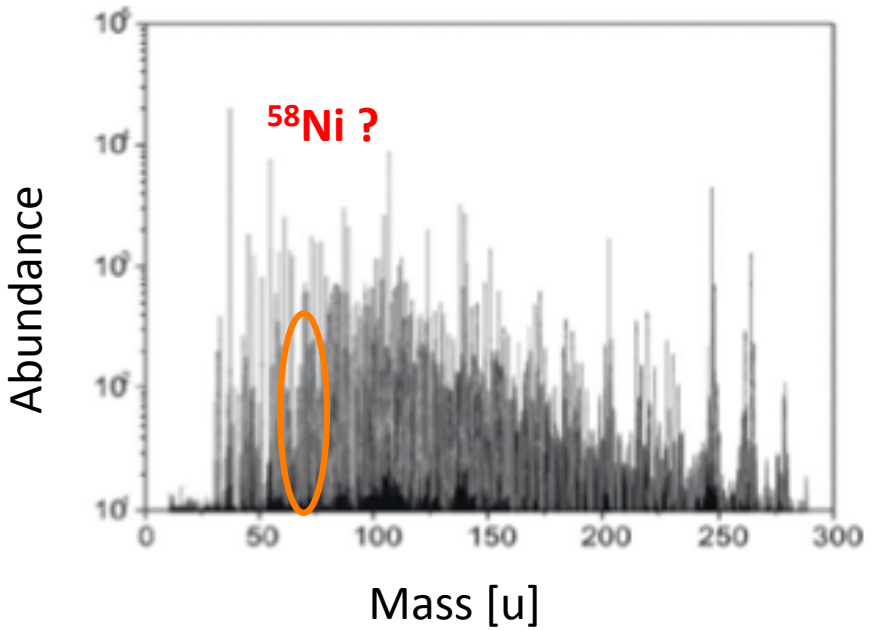
$\sigma_R / \sigma_{R0} = 0.2 - 0.3$

What's coming out from the Gas Cell?

Everything !!!

that transported by the RF repelling structure

- Adducts and molecules
- Isotopic/Isobaric contamination



Solution

Cryogenic Operation→ (buffer gas purification by Cryo-sorption)

Operate He-filled stopping cell at cryogenic temperature (~70 K)

- Ultra-pure helium (freezing-out of contaminants)
  - Ideal for ion survival, 2+ charge state possible
  - No formation of molecules/adducts
- Reduced radial ion diffusion
- Reduced requirements for cleanliness → easier, more flexible construction
- Operational reliability

P. Dendooven et al., NIM A 558 (2006) 580
S. Purushothaman et al., NIM B 266 (2008) 4488

Cryogenic Stopping Cell

Design

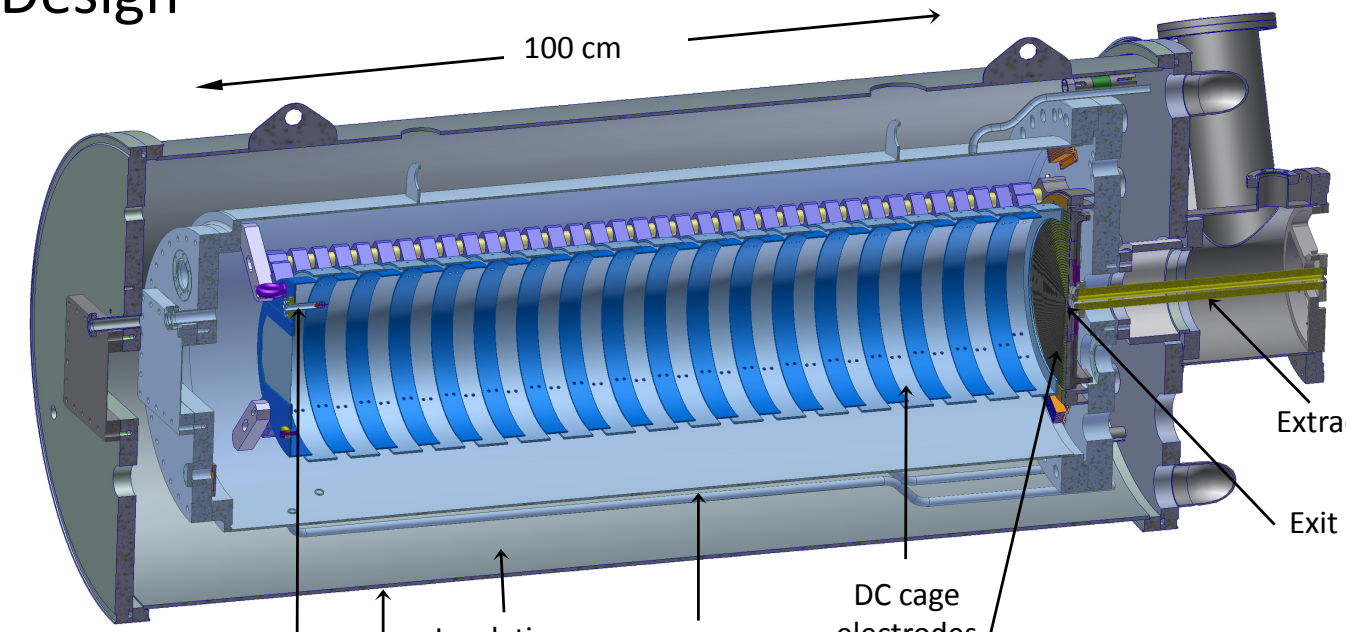
Developed in Collaboration

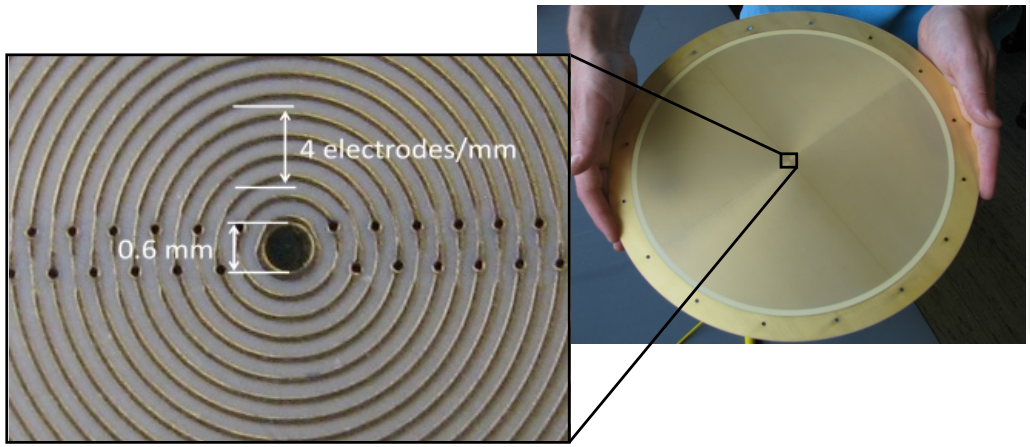
Kernfysisch Versneller Instituut

university of groningen

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

GSI





High-density Operation

PCB-based RF carpet

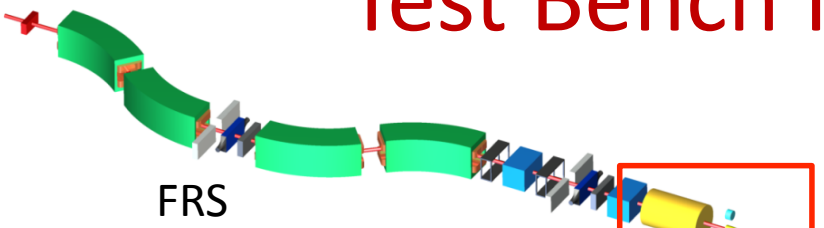
Small spacing ➔high RF repelling field

- High stopping gas densities
- Less complex construction than RF funnels

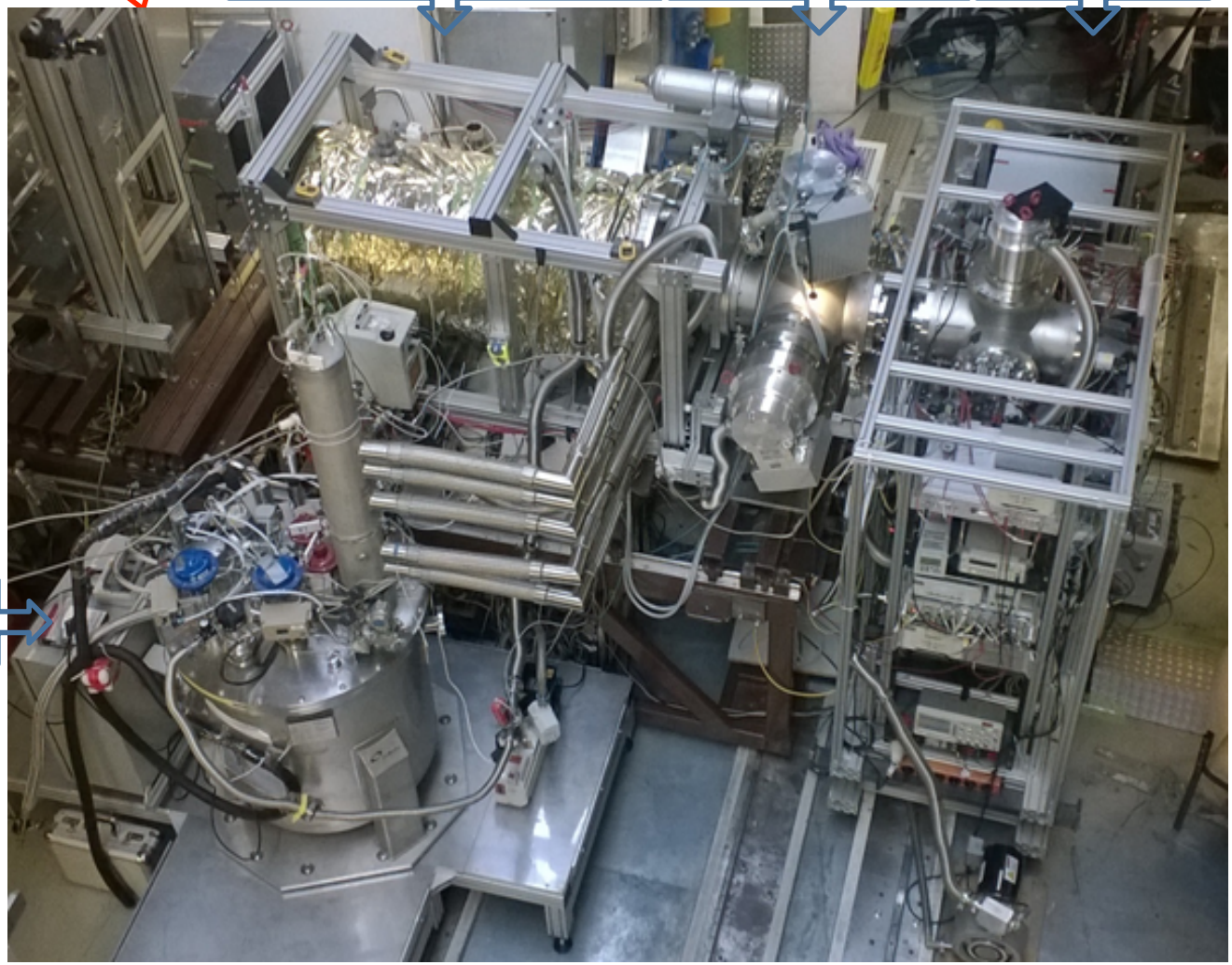
M. Wada et al., NIM B 204 (2003) 570

M. Ranjan et al., Europhys. Lett. 96 (2011) 52001

Test Bench for LEB of Super FRS @ FAIR



FRS Ion Catcher setup



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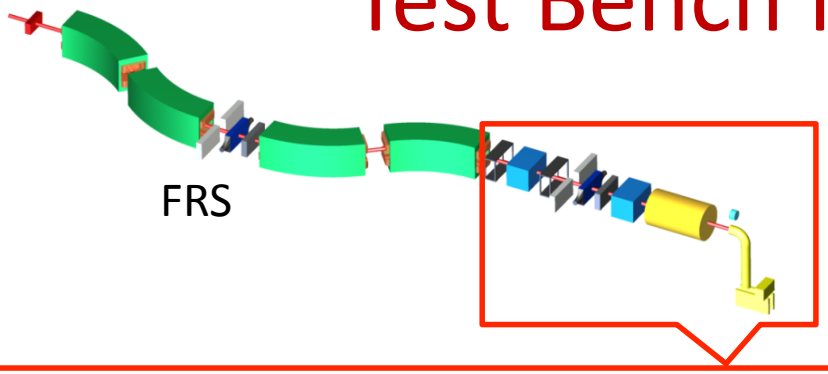


FRS Ion Catcher setup

Range bunched ions from FRS

TPC 1

TPC 2

Scintillator Sc41

Alpha Tagger

Si Detector

MUSICs (Mü 1+2)

Slits

Degrader (Wedges)

MUSIC43

Channeltron detector

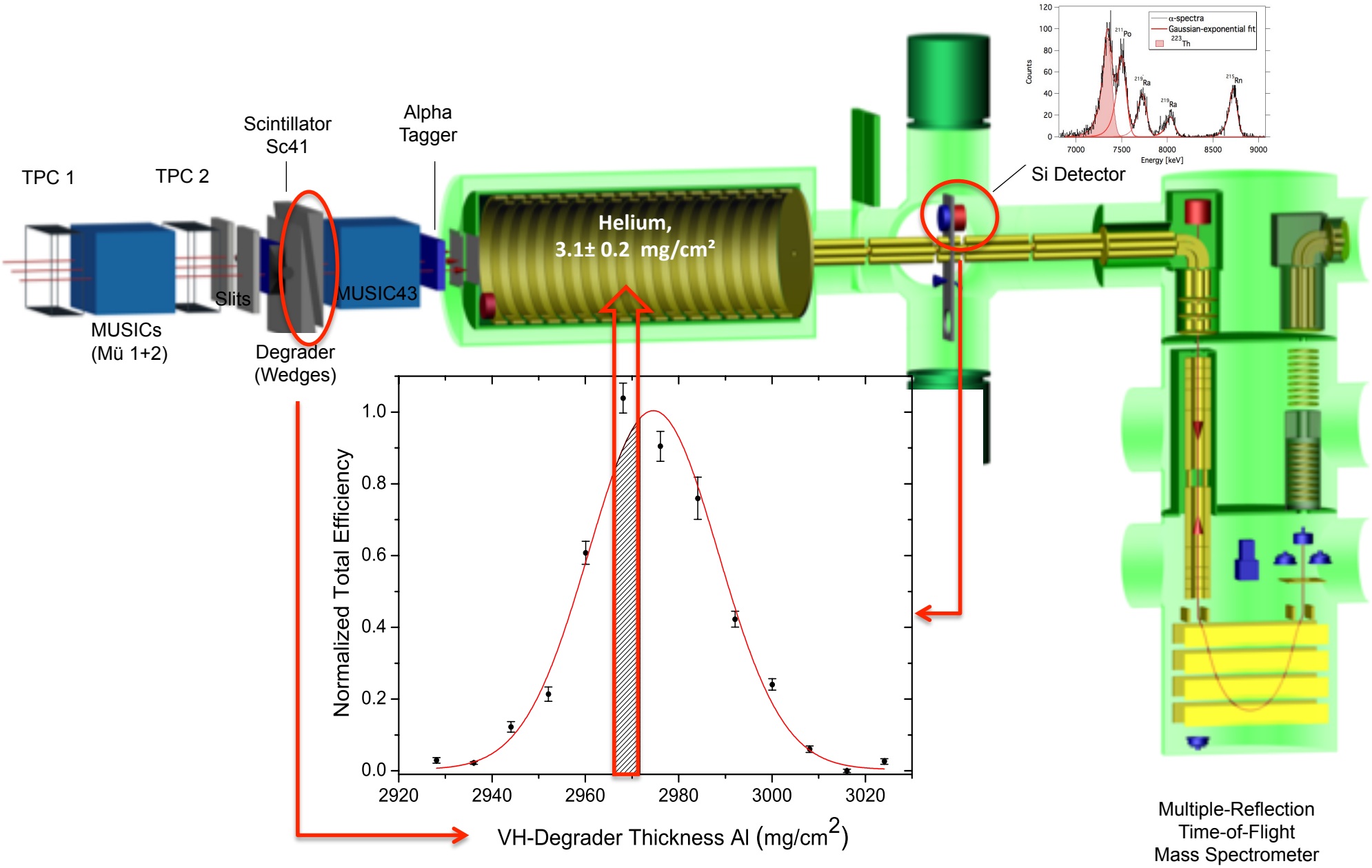
Cryogenic Stopping Cell
(Helium, 50 mbar, 75 K)

Diagnostics Unit
Differential pumping
Beam transport
Identification
RFQ Mass filter

Multiple-Reflection Time-of-Flight Mass Spectrometer
- Broadband mass spectrometer for diagnosis of the CSC
- High precision mass measurements of short-lived nuclei
- Isobar separation with high ion capacity

W.R. Plaß, et al., NIMB 317 (2013) 457-462

FRS Ion Catcher Results: Stopping Efficiency

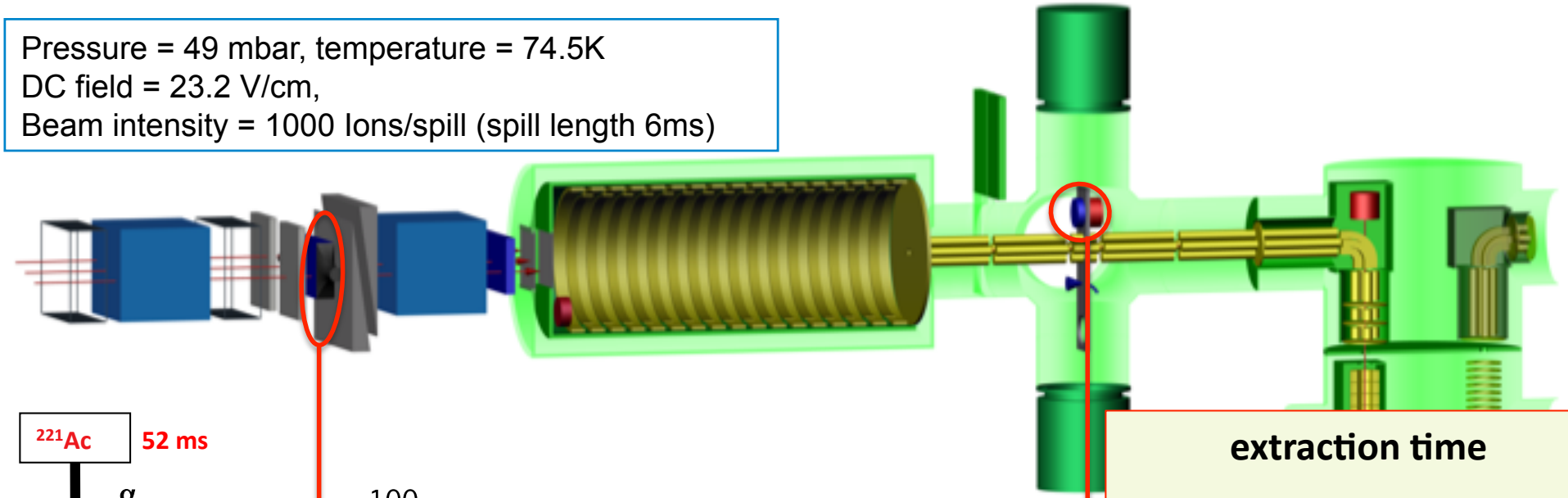


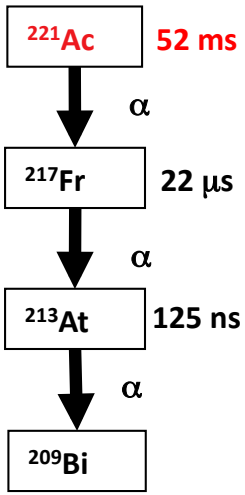
Range distribution of ^{223}Th

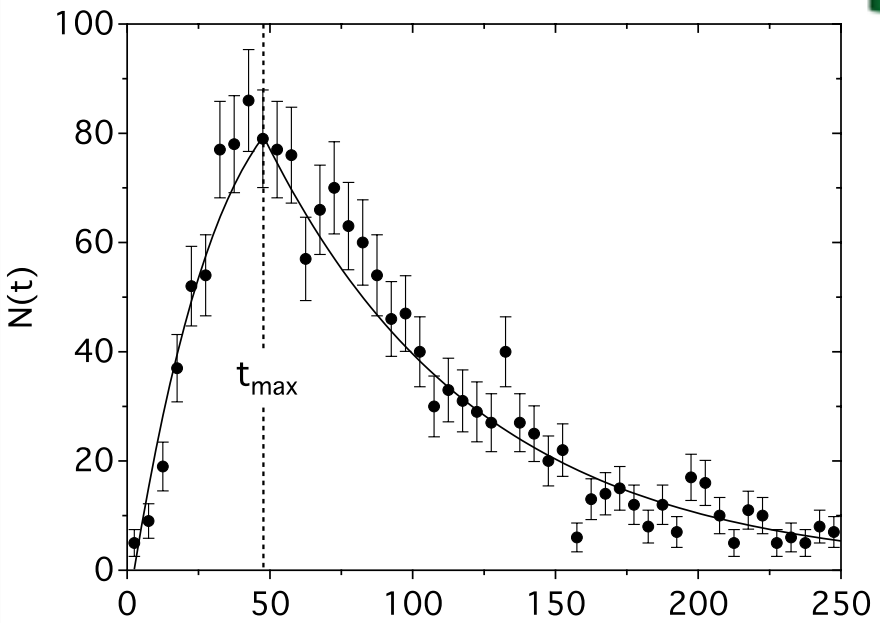
S. Purushothaman et al, EPL 104 (2013) 42001

FRS Ion Catcher Results: Extraction time measurement

Pressure = 49 mbar, temperature = 74.5K
DC field = 23.2 V/cm,
Beam intensity = 1000 Ions/spill (spill length 6ms)







Scintillator time stamps

Si detector timing output

extraction time

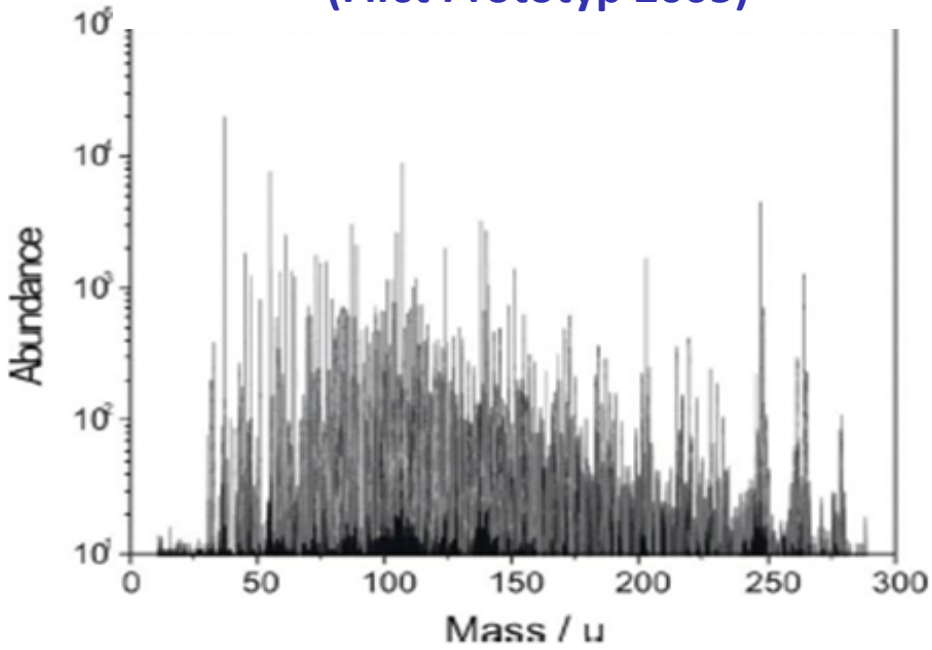
- **off-line**
  ~ 25 ms
- **on-line**
  ~ 24 ms
- **Theory (K_0=17.5 cm²/Vs)**
  ~ 27.5 ms

S. Purushothaman et al, EPL 104 (2013) 42001

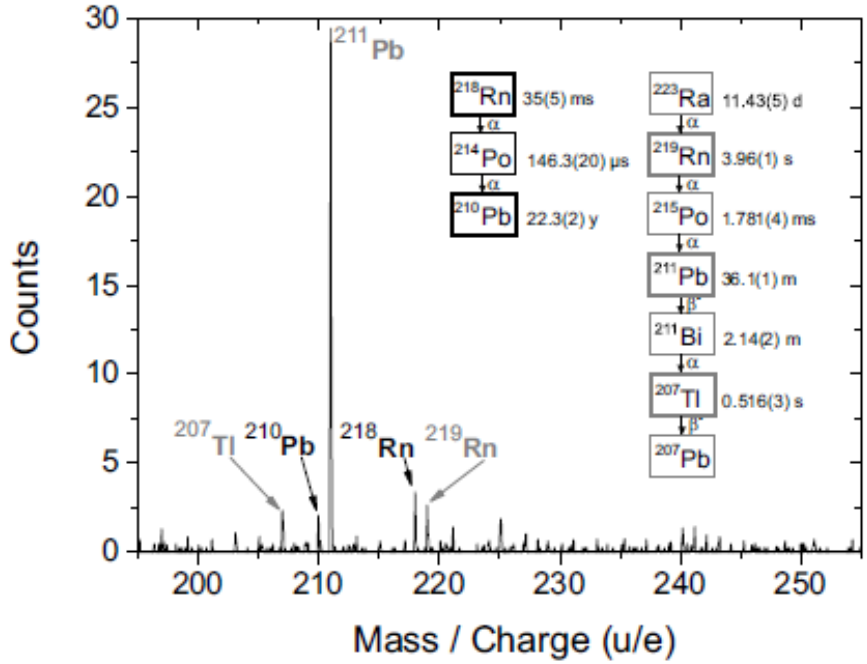
FRS Ion Catcher Results: Cleanliness of the CSC

MR-TOF-MS (Broadband Measurement)

Online with Beam
(First Prototyp 2005)



Online with ^{218}Rn Beam
and ^{223}Ra recoil source



- Broadband mass spectrometry is a necessity for quick and reliable operation of a stopping cell
- Molecular contaminants / adduct formation are not a problem for the cryogenic stopping cell

Many orders of magnitude cleaner compared to
2005 GSI experiment (ANL cell)

Recent Results: Stopping and Extraction Efficiencies

Stopping Cell Efficiencies for U-fragments (^{223}Th, ^{221}Ac, ^{219}Rn)

- Areal density up to 5 mg/cm² (He)
  - almost two times higher gas density compared to other stopping cells using an RF structure

- Stopping efficiencies up to 27%
  - unprecedented for relativistic ions

- Ion survival and extraction efficiencies up to 62%
  - compares favorably to other stopping cells world-wide

- Ion survival and extraction efficiencies are element-independent
  - inherent advantage over ISOL facilities

- Total efficiency up to 14.5 %
  - unprecedented for relativistic ions

S. Purushothaman et al., EPL 104 (2013) 42001

Future plans

For 2014 beam time

- High intensity operation, space charge and plasma limitations
- Test with fission fragments (large emittance, low mass)

TDR for third generation stopping cell for LEB at FAIR

Acknowledgements

F. Amjad[2], S. Ayet[2], T. Dickel[1,2], P. Dendooven[3], M. Diwisch[1], J. Ebert[1], A. Estrade[2], F. Farinon[2], H. Geissel[1,2], F. Greiner[1], E. Haettner[1], C. Jesch[1], N. Kalantar-Nayestanaki[3], R. Knoebel[2], J. Kurcewicz[2], J. Lang[1], I. Moore[4], C. Nociforo[2], M. Petrick[1], M. Pfuetzner[2], W.R. Plaß[1,2], S. Pietri[2], A. Prochazka[2], S. Purushothaman[2], M. Ranjan[3], M.P. Reiter[1], A.-K. Rink[1], S. Rinta-Antila[4], C. Scheidenberger[2], M. Takechi[2], Y. Tanaka[2], H. Weick[2], J.S. Winfield[2], M.I. Yavor[5]

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[2] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
[3] KVI, University of Groningen, The Netherlands
[4] University of Jyväskylä, Jyväskylä, Finland
[5] Institute for Analytical Instrumentation, RAS, St. Petersburg, Russia

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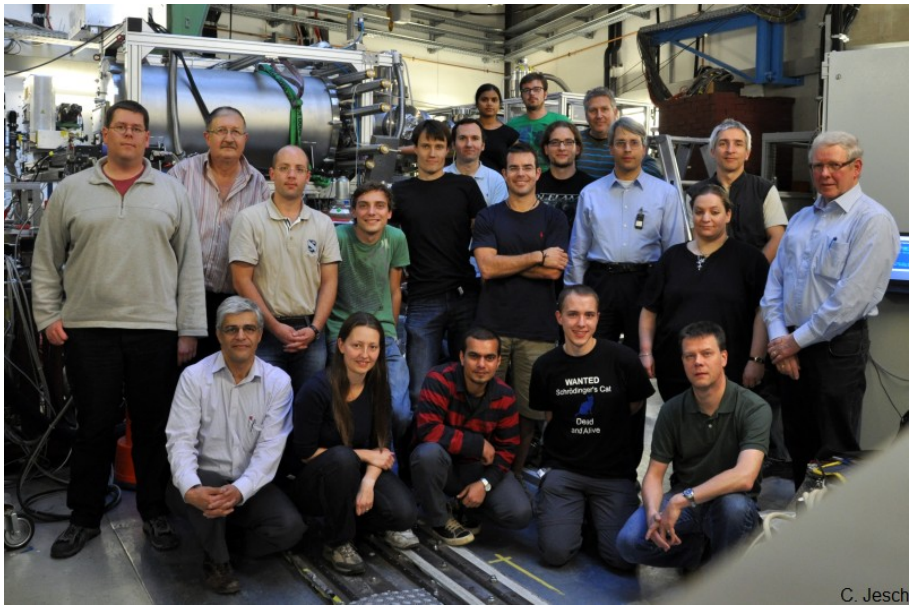

Stopping Cell Design

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Operate He-filled stopping cell at cryogenic temperature (~70 K)

- Ultra-pure helium (freezing-out of contaminants)
  - Ideal for ion survival, 2+ charge state possible
  - No formation of molecules/adducts
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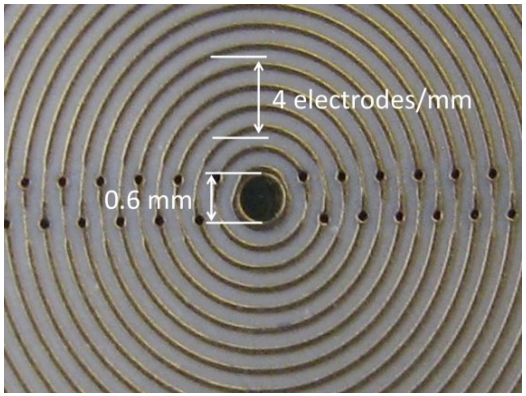
P. Dendooven et al., NIM A 558 (2006) 580
S. Purushothaman et al., NIM B 266 (2008) 4488

High-density Operation
Use RF structure with small spacing to achieve high RF repelling field
(PCB-based RF carpet instead of RF funnel)

- High stopping gas densities
- Less complex construction than RF funnels

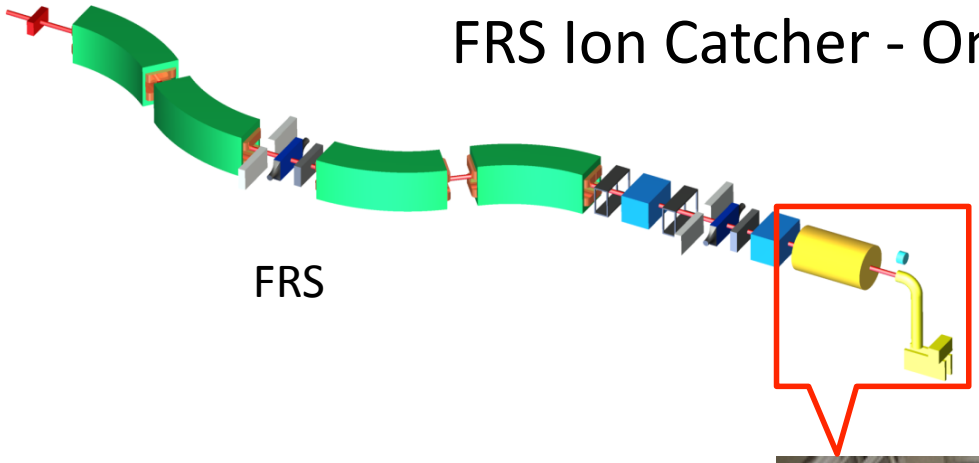


M. Wada et al., NIM B 204 (2003) 570
M. Ranjan et al., Europhys. Lett. 96 (2011) 52001

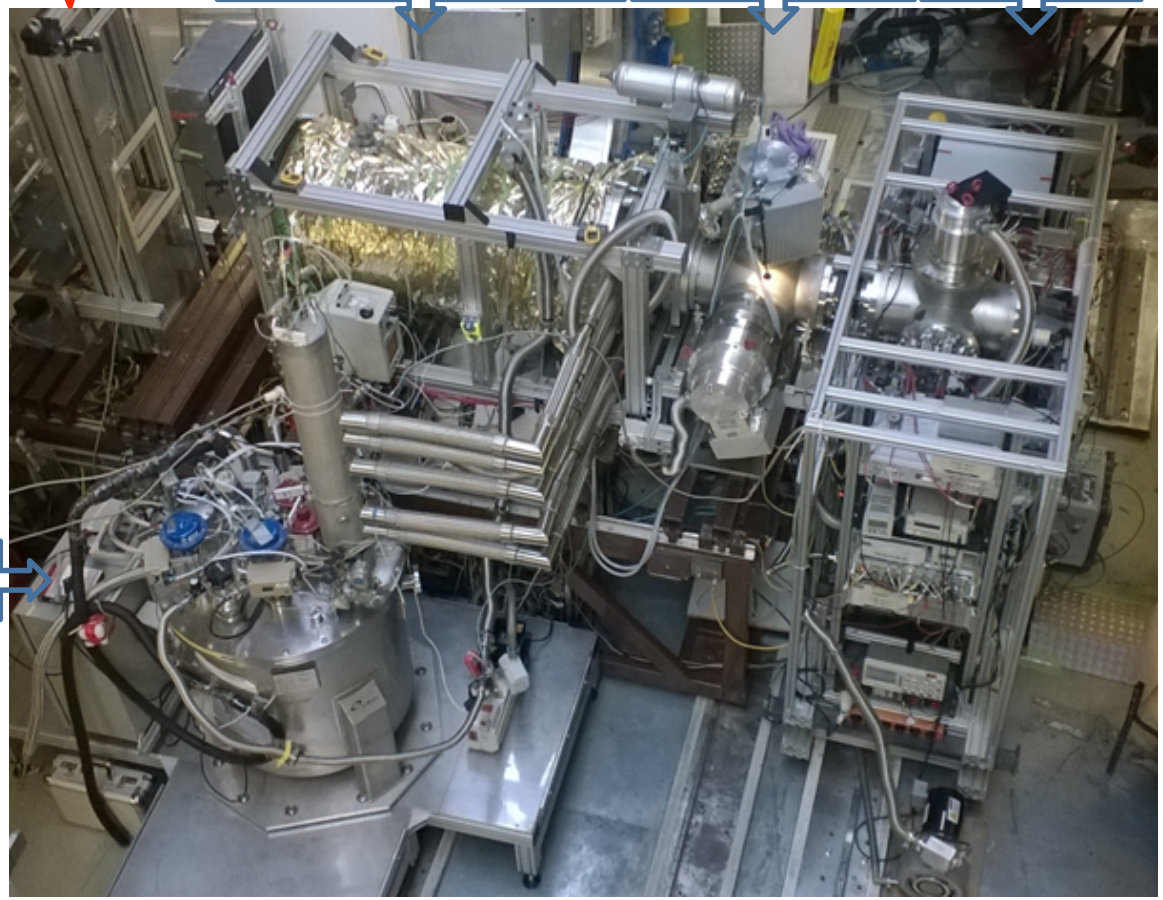
Diameter:	250 mm
Electrode spacing:	0.25 mm

Test Bench for LEB of Super FRS @ FAIR

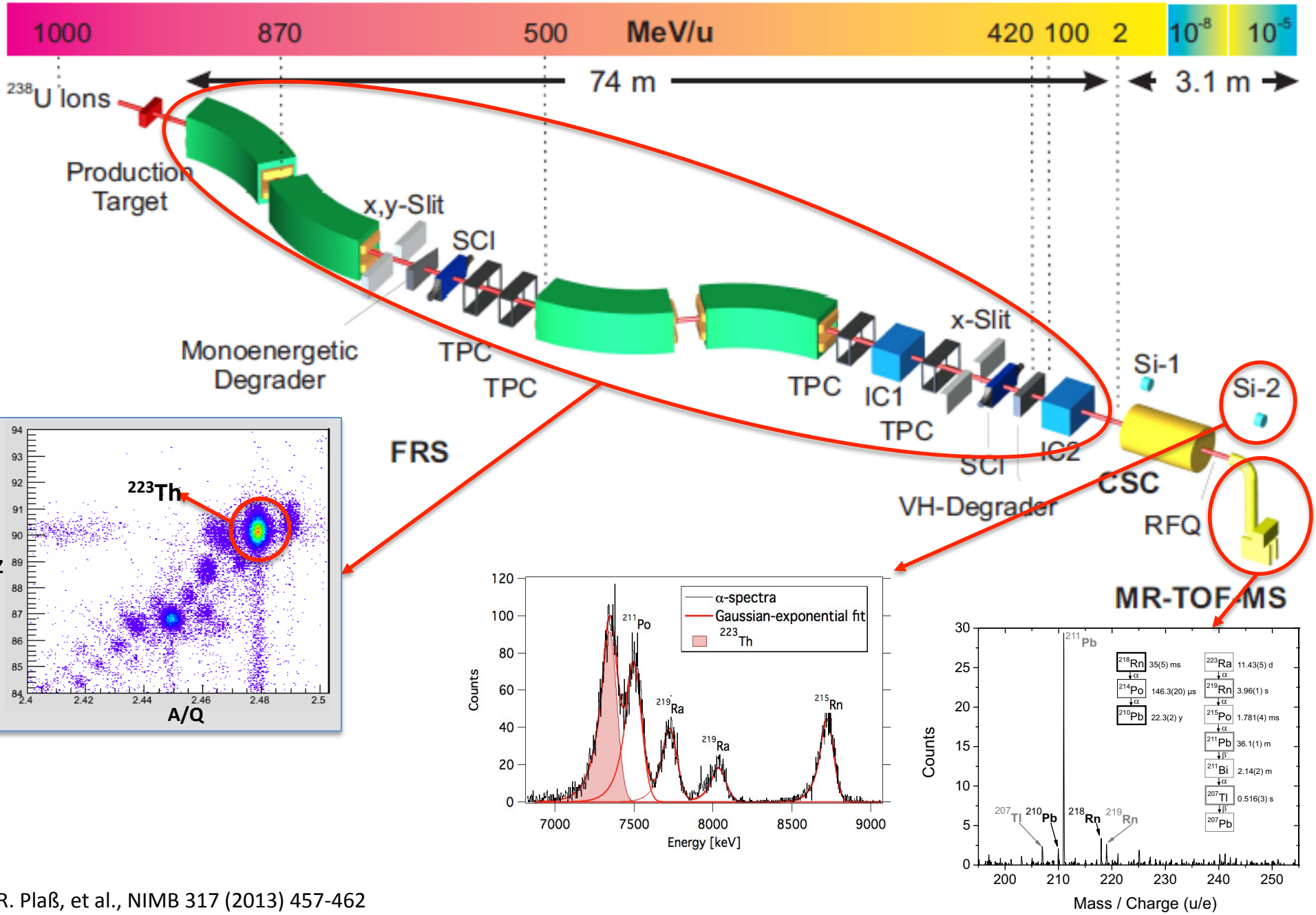
FRS Ion Catcher - Online in October 2011 and July 2012



FRS



FRS ion catcher setup (a test bench for LEB at FAIR)



W.R. Plaß, et al., NIMB 317 (2013) 457-462

Novel Concept: **High Density** Stopping Cell

Large axial DC field → fast extraction

$$v_z = K \times E_z^{DC}$$

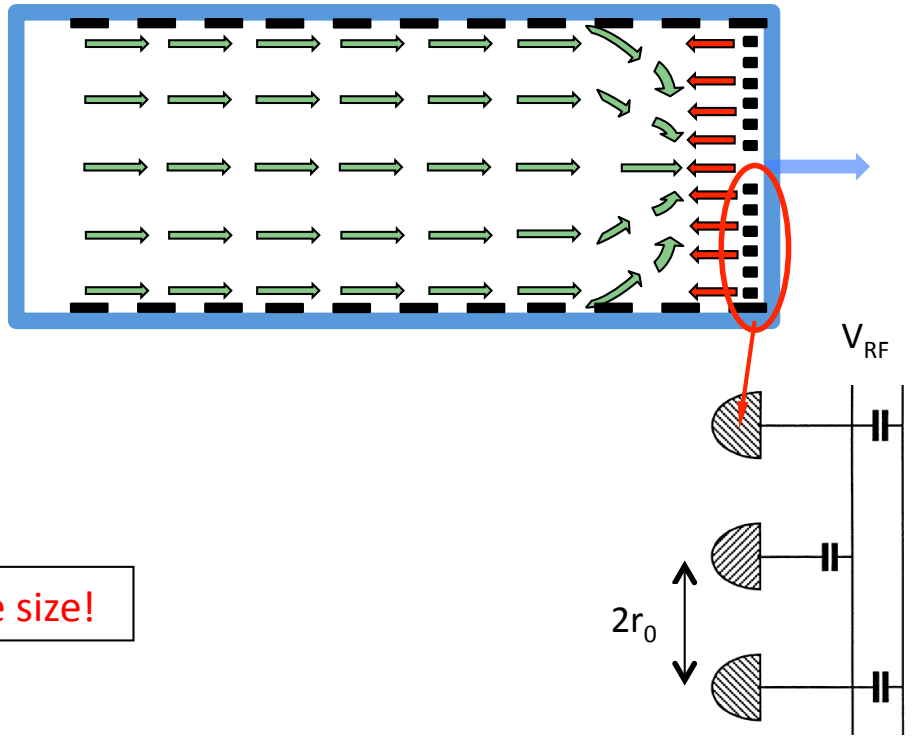
Effective RF field repels ions from electrodes

$$E_{eff} \propto K^2 \frac{m}{q} \frac{V_{RF}^2}{r_0^3} \propto \frac{qm}{n^2} \frac{V_{RF}^2}{r_0^3}$$

limited by discharges

reduce structure size!

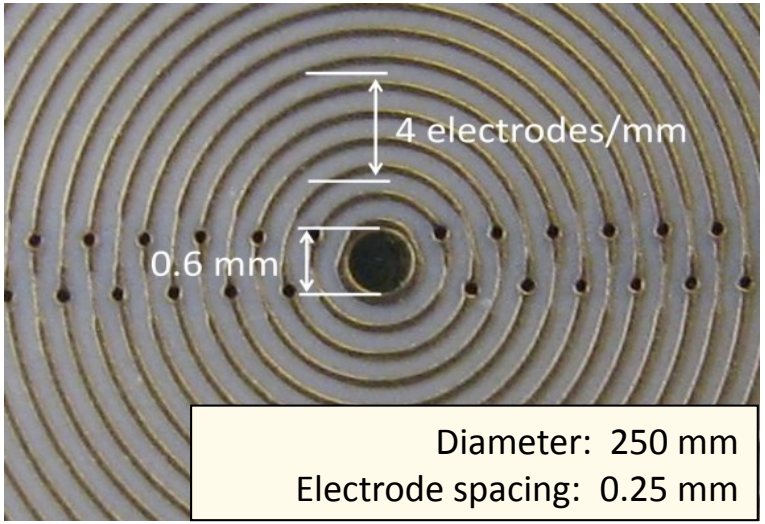
high gas density → reduction of effective field



Use RF structure with small spacing (PCB-based RF-carpet) to achieve high RF repelling field

(4 electrodes/mm compared to 1 electrode/mm)

- High stopping gas densities
- Less complex construction than RF funnels



A. Tolmachev, Int. J. Mass Spectrom. 203 (2000) 31
M. Wada et al., NIM B 204 (2003) 570

Efficient stopping

Range & range straggling